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ANALYSIS OF A LARGE HIGH PRESSURE VESSEL CLOSURE

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The design of the end closure for a high pressure vessel is never an easy task. However, in this case it is complicated by a requirement for quick operation and high reliability. The configuration which has best proven itself many times is the screw block breech. This report covers an analysis of this closure which is a five-body problem. The problem is further complicated by the fact that the bodies interact on eight contact surfaces. This analysis will point to a fatigue failure at a single point in the structural system.

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INTRODUCTION

Over the years the design of screw block breech closures has been done on a 'rule-of-thumb' basis. The breech is the high pressure closure on the crew end of a cannon and as such is a critical element in the overall safety of any cannon system. The last major design study was done in 1962 and resulted in the formulation of the current 20-degree Benet Buttress thread form which has been used on all cannons designed in the U.S. since its development (refs 1-3). Other than this one item there has been little change in configuration between different designs. Some additional information has been obtained by three-dimensional photoelastic methods and resistance strain gages, but these efforts have largely been limited to new configurations. These new configurations have seen limited use and the major improvements have been in efforts to improve the available steels. However, the steady drive for increased performance has pushed the breech pressures to new higher levels and current test results have produced unacceptably low values for fatigue life.

Therefore, a new and stronger closure is needed and the design was undertaken several years ago. Recently Benet Laboratories acquired the ABAQUS (ref 4) nonlinear finite element code which has powerful interface elements. These elements allow the analysis of the full breech closure and eliminate the use of load assumptions at the joints between the various components. This is very important in this problem which involves the interaction of five components along eight different contact surfaces. To make things more complicated, two of the surfaces are in reality screw thread connections and three others are provided with an initial gap that may close at elevated pressures. The overall

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References are listed at the end of this report.

result is that the problem becomes nonlinear because the state of the contact surfaces can vary with load. These variations are indeed a reality as they are in many other threaded connection problems.

The analysis reported here includes some of the results from the first major analysis of a complete breech closure. The analysis was done as an axisymmetric solution and yielded information on several features of the structure that had never been considered before. These new effects were found in spite of the fact that the structure is not actually axisymmetric and the analysis must ignore two design features which would require full three-dimensional analysis. First is the helix angle of the screw threads, which would not seem to result in a large error. The second item is that the screw threads are interrupted threads to allow for faster operation between pressure cycles. In this process about one-half of the threads have been removed in four areas around the pitch cylinder of the threads, resulting in an overall reduction in the threaded surface of about 50 percent. Along with this area reduction is a periodic variation in deformations as strain gage results plotted around the central axis of the closure. This effect has not been reported for this system, however, it was reported for a similar one by this author in a photoelastic study (ref 5). Despite these problems, this analysis has proven very useful.

GEOMETRY

This problem is the analysis of a high pressure end closure for a tubular pressure vessel. The closure is sealed with a Bridgman unsupported area seal which uses a large elastomer obturator pad (P) as the primary seal. The obturator pad is forced into a 'pad seat' at the end of the cylindrical tube (T) by the action of an obturator spindle (S). This seal is supported by a block (B) which is attached to the tube by a ring (R). The entire structural system contains hot high pressure gasses and is shown exploded in Figure 1 and as a fully assembled finite element mesh in Figure 2.

The basic finite element grid in Figure 2 was used for the analysis with CAX8 axisymmetric elements. The five components modeled are the tube, ring, block, spindle, and obturator pad. In this picture it is not easy to see the separate components because all of the gaps are very small relative to the overall structure size. At the top of the plot is the tube which runs down into the ring. The ring is the component on the right side of the plot and serves as the primary structural connection between the tube and the block at the bottom of the plot. The spindle is on the left of the plot and is the primary load transfer device in the Bridgman unsupported area seal. The total axial load of the system is applied to the top of the spindle and transferred through the obturator pad to the block. This process forces the pad to press in the tapered seat in the tube and seal the high pressure gas. Thus the pad interacts directly with the tube, block, and spindle. The tube-ring and the ring-block connections are the threaded surfaces where the screw threads are shown as a series of long thin elements. The two threaded surfaces and the three surfaces around the pad are modeled with zero initial gap which is close to the actual case as there is a small preload on these surfaces at zero pressure. This is not the case for the three pilot (guide) surfaces. Two of these are between the ring and the tube and one is between the block and spindle.

LOADS AND CONSTRAINTS

The boundary conditions in this problem are rather simple and comprise one boundary condition and two pressure loads of equal magnitude. The constraint is that the axial displacement of the tube is constrained to zero, at the top of the picture, to prevent axial movement of the structure. The uniform pressure loads are defined for the top surface of the spindle and the inside of the tube.

CONTACT SURFACES

The six normal contact surfaces in this structure were modeled using the ABAQUS three-node interface element (INTER3A). The three pilot surfaces required only one element each and the initial gap was built into the node point coordinates. The interfaces between the pad and the other three components required either three or six elements each. Because these are independent surfaces, care was required to insure that they would act independently.

SCREW THREAD SURFACES

One object of this analysis was to demonstrate the contact surface. This concept was started as the macro-modeling approach of Bretl (ref 6) and has been expanded here to produce a more detailed model of the surface. The method starts by replacing the screw threads with an equivalent orthotropic continuum (the long thin elements) where the orthotropic properties are derived from the detailed analysis of a single screw thread. This process greatly reduces the complication of the analysis over any attempt to model individual threads. While this is a good start, the interface kinematics must also be modeled.

The ABAQUS one-dimensional interface and gap elements (INTER1 and GAPUNI) are used to model kinematics in the following way. The primary contact surfaces of the threads are modeled using one-dimensional interface elements to connect pairs of nodes on the two components. The surface normal for these elements is defined normal to the contact surface of the thread. This definition is also required because the two points are at the same point in space i.e., zero gap. Because the tube threads are to be driven into ring threads by the pressure load, the back surface of the threads is modeled using gap elements where the initial gap is defined independently from the node position. Here the surface normal is also defined normal to the contact surface. These kinematic conditions are more important to good results than the equivalent continuum modeling of the threads.

THREAD FILLET STRESSES

In this analysis the details of the individual threads have been smeared into an equivalent orthotropic material and a set of kinematic conditions which define a complex contact surface. The resulting stresses are nominal values which must be related to the actual thread fillet stresses by a stress concentration method (ref 7). This method uses three nominal stresses, the shear transfer, the radial stress, and the axial stress in the base material. The shear transfer and radial stresses are the same for each side of the threaded connection and are obtained by averaging stresses in the equivalent orthotropic material of the two components. The axial stresses are different in each component and are obtained from elements which use conventional material properties. The stresses from ABAQUS are output at Gauss stations and all stresses are taken directly from these data using the closest available Gauss station.

The CAX8 element uses three Gauss stations in the axial direction and each threaded contact surface has six elements. This combination will give fillet stress data for 18 positions along each threaded connection. Because the axial stress is different for each side of each connection, there will be four independent plots of fillet stress versus position in this problem. These include a plot for the internal and external threads on the tube end and the block end of the system.

RESULTS

This is an extremely complicated problem which can yield many different results depending on the goals of the analysis. Some highlights of the full results have been selected and are depicted by the five figures shown. These consist of a single deformed mesh plot, three stress contour plots, and a single plot of tensile fillet stress in the thread fillets versus thread position. The most convenient stress units for this problem are the nondimensionalized stresses, or stress divided by internal pressure. These will be used in all cases except the stress contour plots where this is not practical in the ABAQUS graphic output.

The deformed mesh plot in Figure 3 shows the simple fact that the elastomer pad is the dominant deformation of the structure. It is so large that many features are not readily visible in this plot. The first of these is that the tube expands into the ring which produces an average radial stress of -0.125. This is in contrast to the radial stress of -0.072 between the ring and the block. This combination will result in a reduction in the thread fillet stresses in the tube end when compared with the block end.

Figures 4 through 6 are stress contour plots of the three principal stresses. ABAQUS orders principal stresses in an ascending algebraic order. This places the high compressive stresses in Figure 4. It is easy to see the single radial stress contour which runs parallel to the inner surface of the tube. This contour then runs out and around the high contact stresses at the pad seal surface. In this case the unsupported area ratio is about 1.60 which defines the magnification in pressure between the gas pressure and the seal pressure.

Figure 6 is the stress contour for the largest principal stress and therefore shows the high tensile stresses. The only place on this plot which demonstrates a classic stress concentration is in the inner fillet of the spindle. The rest of the structure seems to have no high tensile stresses because the screw thread fillets have been smeared out and do not show.

Figure 7 is the result of the calculation of thread fillet stresses from stress concentration surfaces. The plot has four independent curves and clearly shows the highest stresses in the system. The stresses in this plot have been nondimensionalized to internal pressure and the position starts at the end nearest the obturator pad seal.

DISCUSSION

This analysis has proven very useful in the definition of strain gage positions for prototype testing. While the strain gage results have not been formally published, the work was used as an aid in the selection of strain gage locations and in verification of the results. The initial measured strains did not correlate with the analysis results and a study was undertaken to discover the reason for the discrepancy. The problem was in the clearance of the rear pilot surface between the ring and the tube. The tube was not within drawing tolerances and was replaced with a correct tube. At that point in time the contact loads on that surface were not accounted for in any design calculations.

A basic objective of any complex structural analysis is to discover the position of the highest stress in the structure, and what is even more important is the position of the next highest stress. In this analysis, the highest stress is clearly in the first internal thread on the block end of the ring. This position corresponds with the results of fatigue tests on many systems of the same type. The next highest point is in the first thread on the tube end and this point may indeed crack, but it has never been the point of primary failure. The high stress concentration in the spindle has shown itself to be a problem only when there is some material problem. The fatigue test results are the result of a long history of regular testing, however, the tests are almost wholly unpublished.

The identification of these high stress concentrations in the thread fillets actually results in little new information that was not common knowledge to the engineering community. However, here they have been calculated, from basic information, in a straightforward way and the solution can be used to easily generate new design information. In the past, data of this quality were only available from three-dimensional photoelasticity. This was done for two full breech systems. One is unpublished and the other (ref 5) is a study of a more complicated system that includes another component in the load transfer path. These studies took about one year to complete and provided data for one pressure and one set of random tolerances. Even with these difficulties, the study in Reference 6 does validate many trends in the present report. First is the trend of the tube end fillet stresses being generally lower than the block end stresses. A second trend, which is validated by photoelasticity, is the higher stresses in the last threads of the tube.

The last point that should be covered is usefulness of the graphic output of finite element codes. This seemingly simple function makes an unbelievable improvement in data transfer to the working engineer. Think of the problems involved in attempting to obtain a good understanding of this problem from a few strain gages on the available surfaces. Three-dimensional photoelasticity is a very graphic method, however, the interpretation of the pictures requires some experience and a great deal of time.

CONCLUSIONS

This analysis has demonstrated that this type of complicated structure can be modeled in a rather simple way and that extremely useful results can be obtained. The ABAQUS finite element code has been shown to be an outstanding tool for this type of work. Further, the modeling of threaded connections by using an equivalent continuum approach seems to be an excellent way to further reduce model complication. These techniques should prove to be very useful in the design of screw block systems.

REFERENCES

1. Weigle, R. E., Lasselle, R. R., and Purtell, J. P., "Experimental Investigation of the Fatigue Behavior of Thread-Type Projections," Experimental Mechanics, Vol. 3, No. 5, 1963, pp. 105-111.
2. Marino, R. L. and Riley, W. F., "Optimizing Thread-Root Contours Using Photoelastic Methods," Experimental Mechanics, Vol. 4, No. 1, 1964, pp. 1-10.
3. Weigle, R. E. and Lasselle, R. R., "Experimental Technique for Predicting Fatigue Failure of Cannon-Breech Mechanisms," Proceedings of the Society for Experimental Stress Analysis, Vol. 22, No. 1, 1965, pp. 47-52.
4. ABAQUS Users Manual, Version 4.6, Hibbitt, Karlsson, and Sorensen Inc., Providence, RI, 1987.
5. O'Hara, G. P., "Photoelastic Stress Analysis of a High Pressure Breech," Watervliet Arsenal Technical Report WTV-7057, Benet Weapons Laboratory, Watervliet, NY, December 1970.
6. Bretl, J. L., "Finite Element Analysis for General Solids and Threaded Connections," Ph.D. Thesis, University of Wisconsin-Madison, 1978.
7. O'Hara, G. P., "Stress Concentrations in Screw Threads," ARRADCOM Technical Report ARLCB-TR-80010, Benet Weapons Laboratory, Watervliet, NY, April 1980.

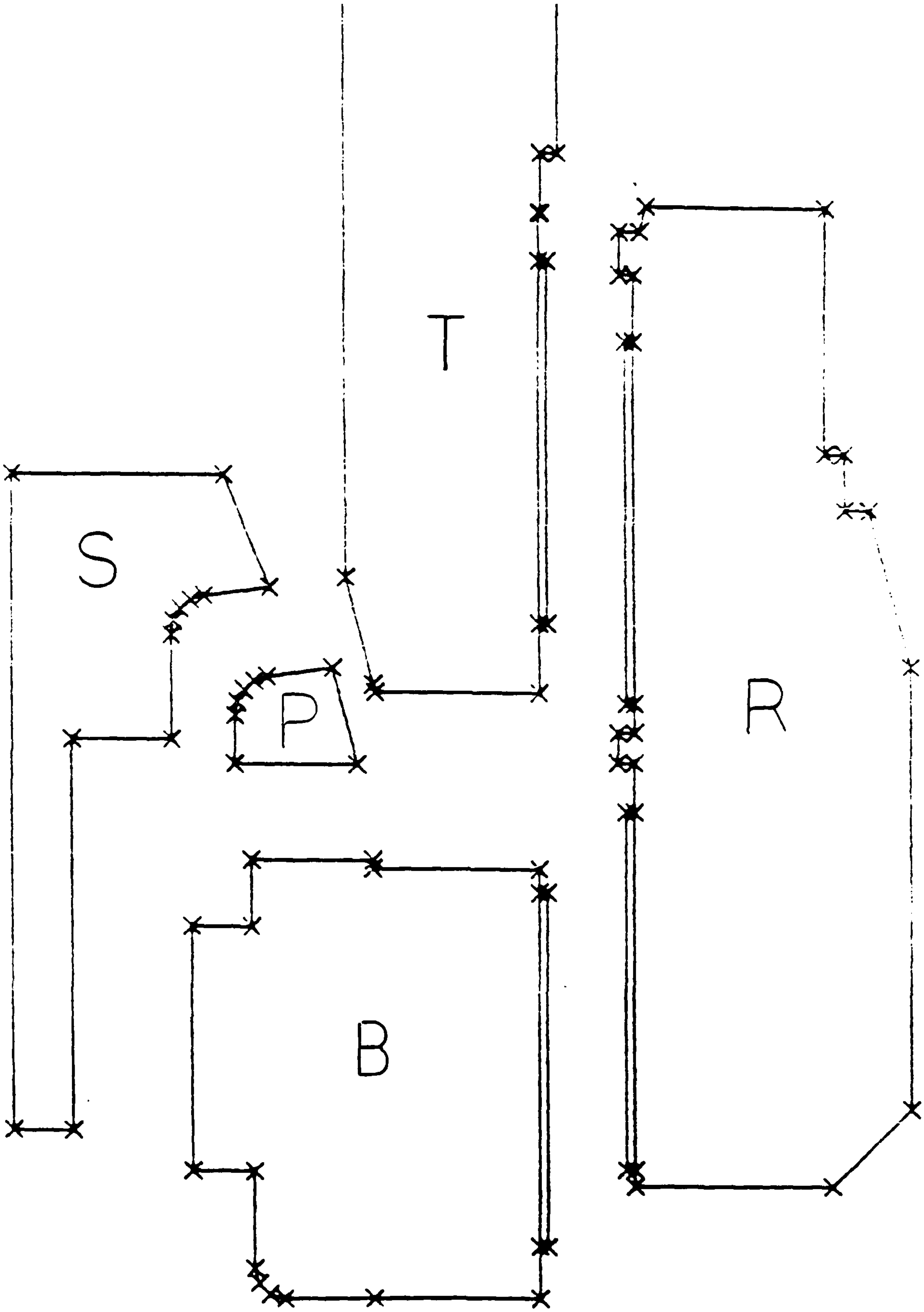

Figure 1. Exploded outline of the components.

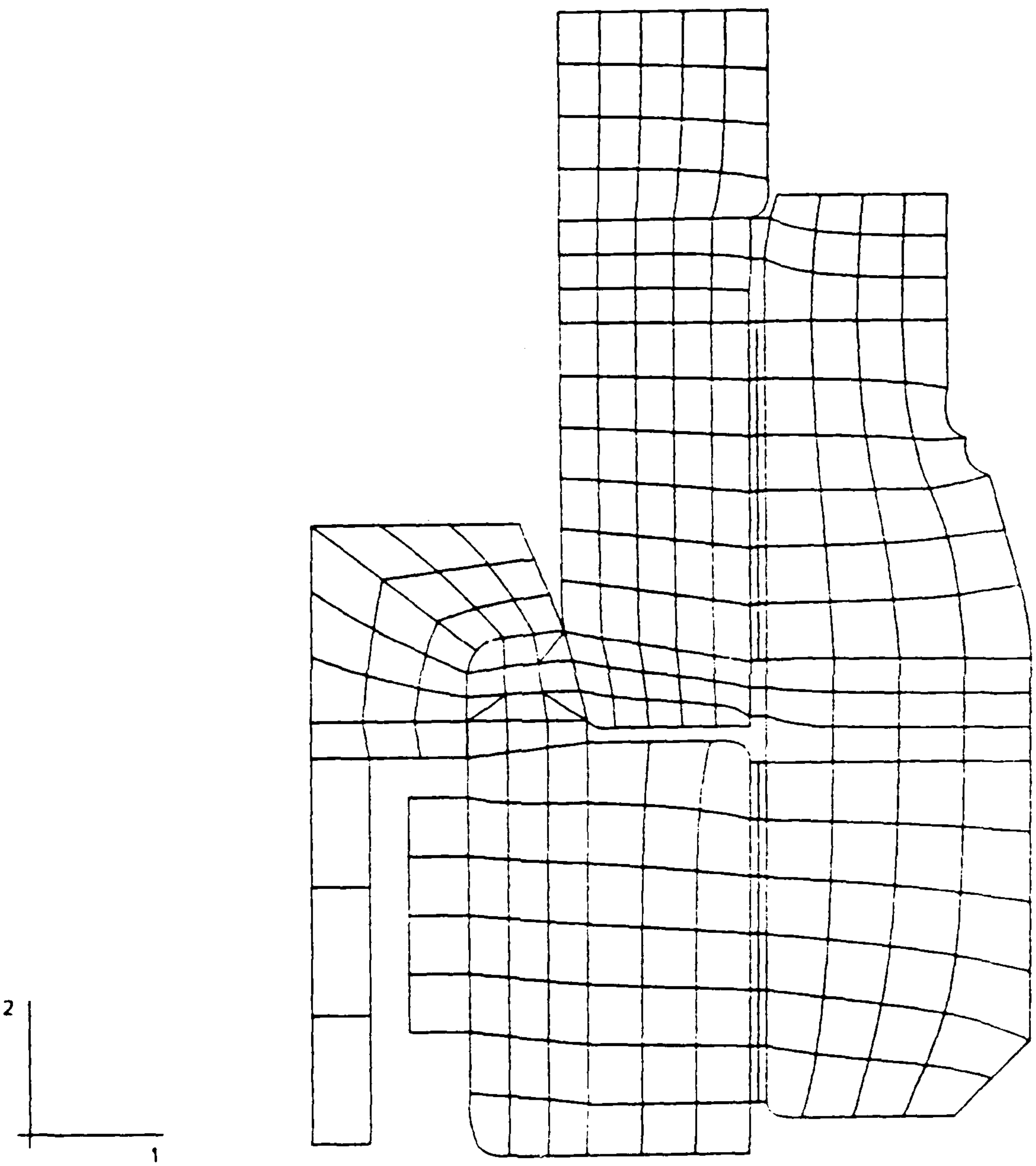

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Figure 2. Undeformed finite element mesh.

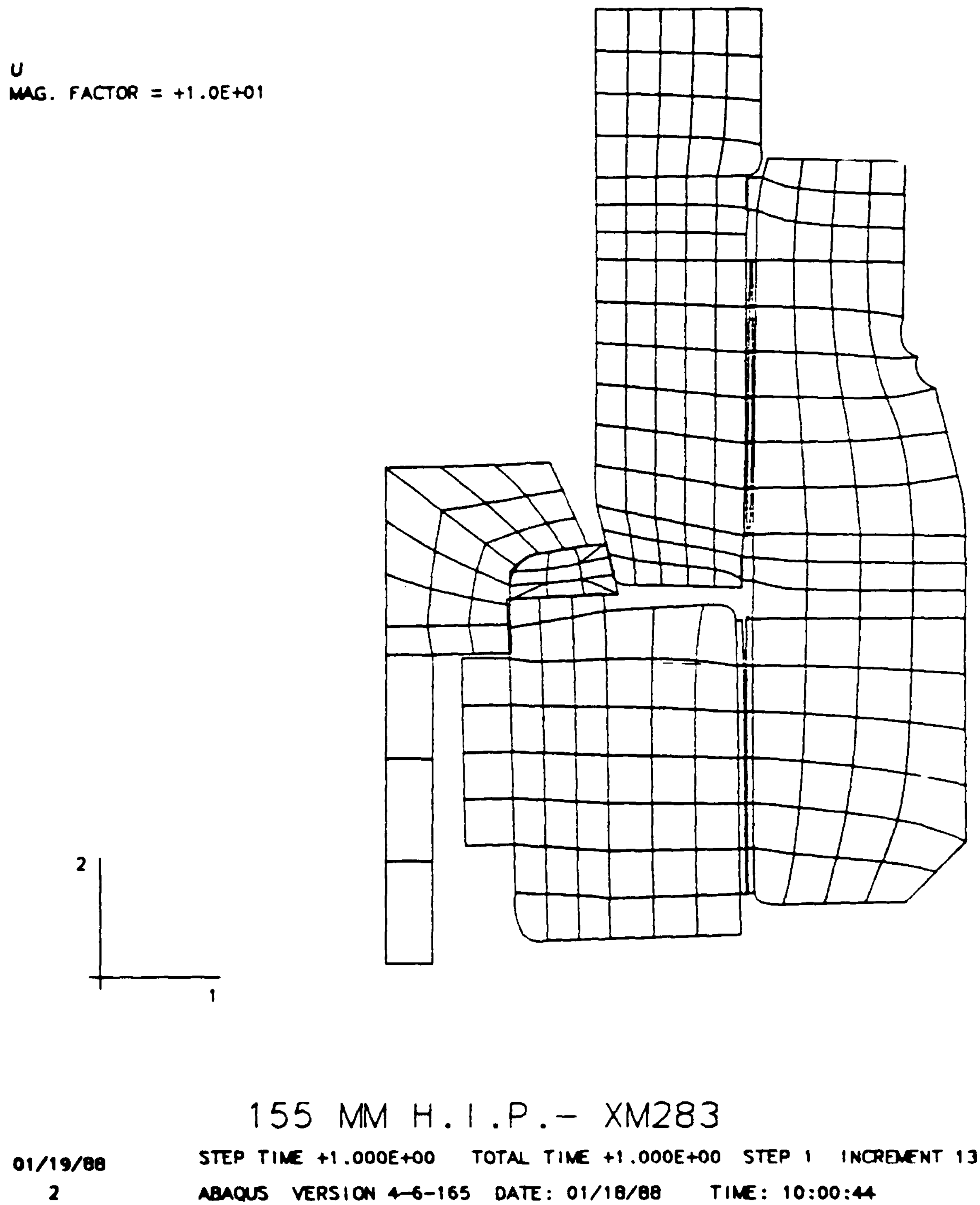

Figure 3. Deformed mesh plot.

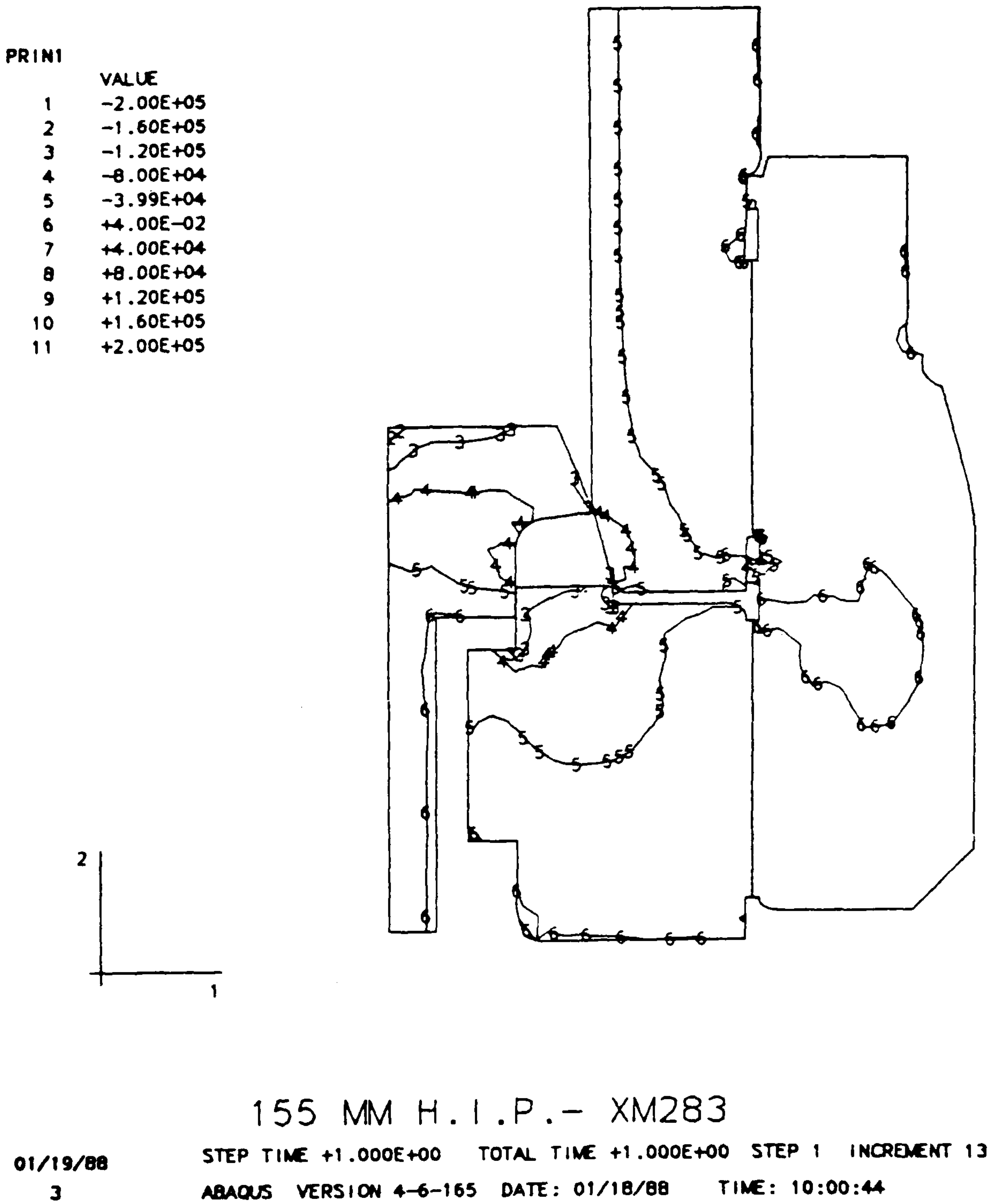

Figure 4. Contour plot of the smallest principal stress.

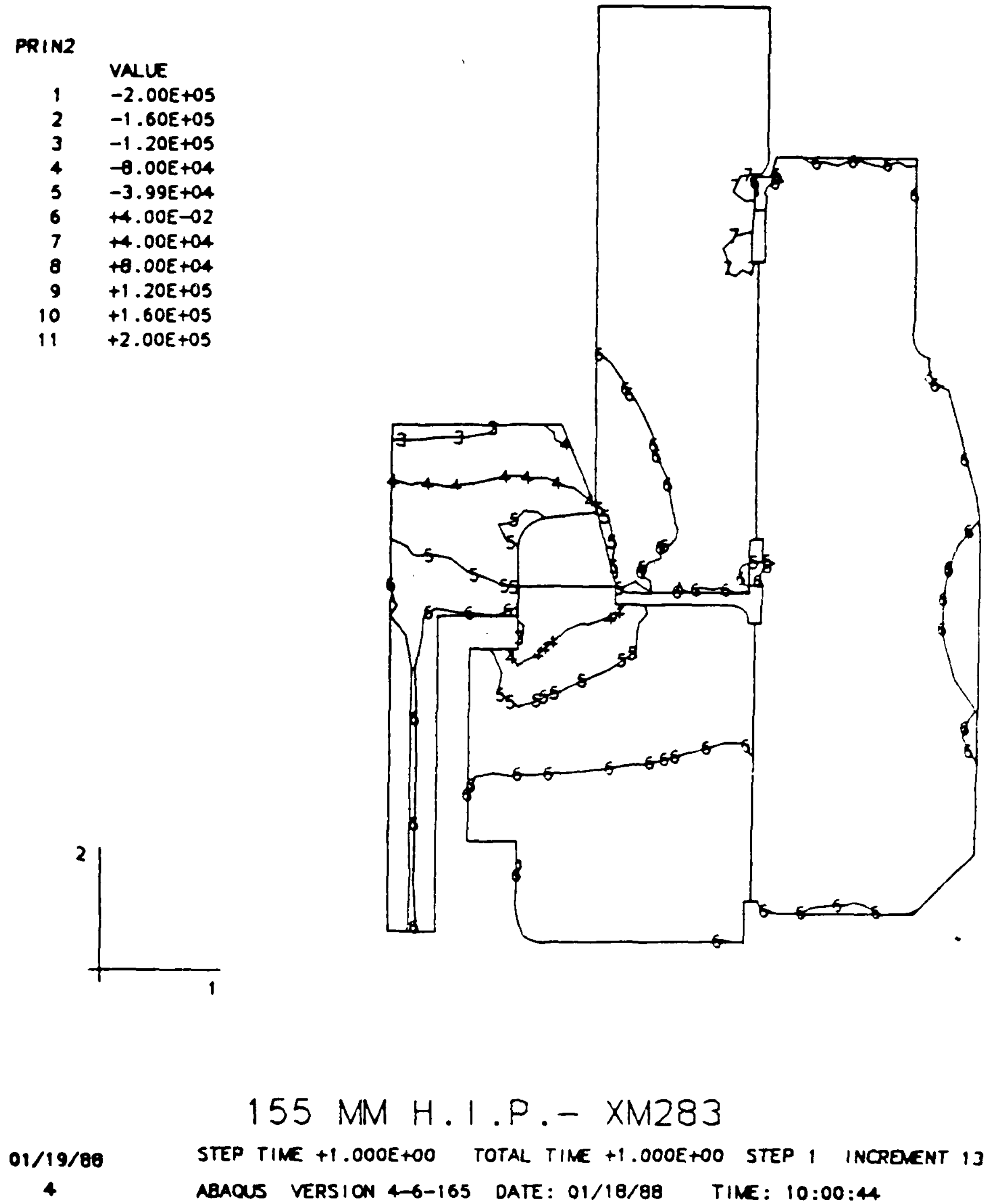

Figure 5. Contour plot of the intermediate principal stress.

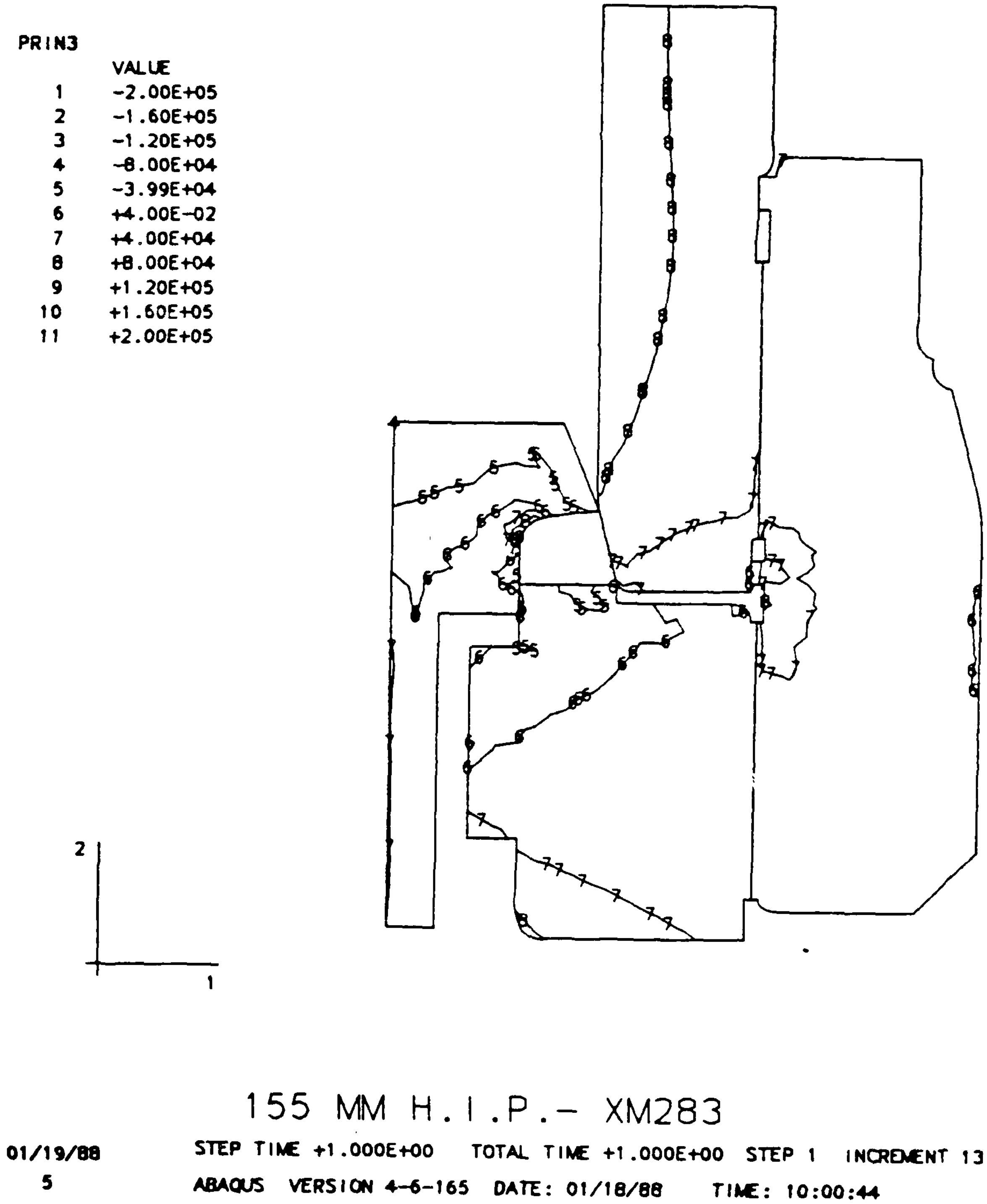

Figure 6. Contour plot of the largest principal stress.

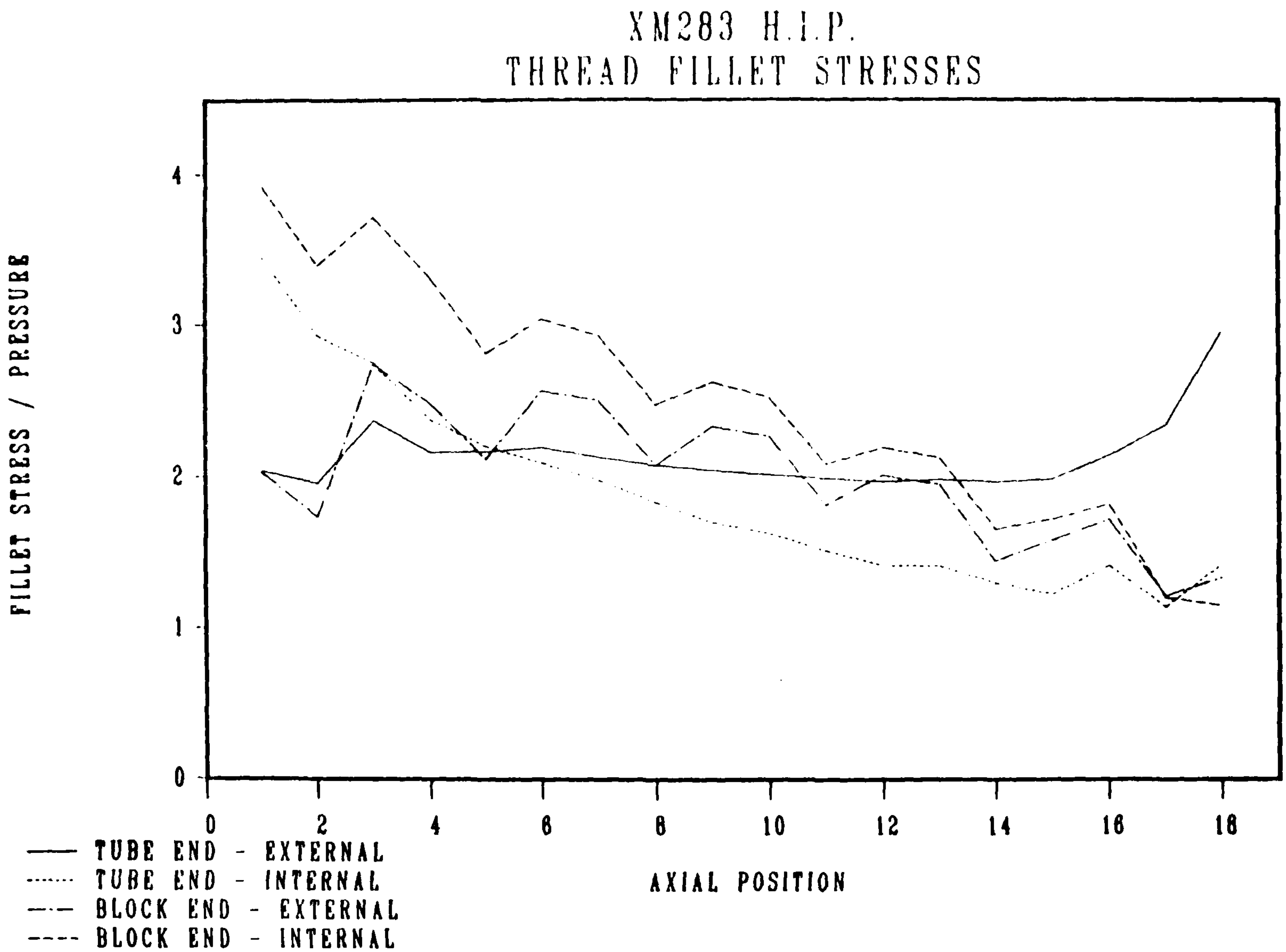

Figure 7. Calculated screw thread fillet stresses.

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